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335 East 45th Street
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AMERICAN NATIONAL STANDARD
Guide to the Experimental Determination of Rotational Mobility Properties and the Complete Mobility Matrix

This Guide is the fourth part of a set of five documents covering the experimental determination of the mechanical mobility of structures by a variety of methods appropriate for different test situations. The present Part IV of the set offers guidance in situations where it is necessary to measure not only translational motion responses to a translational exciting force but also the rotational and combination terms of the 6×6 mobility matrix required to fully describe each point of a structure. This part of the set is published as an ANSI Guide rather than as a Standard because the state of the art of rotational motion and force measurement is still in flux. Several methods are described, all requiring attached exciters.

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This guide was approved by the American National Standards Institute as ANSI S2.34-1984 on 6 July 1984.

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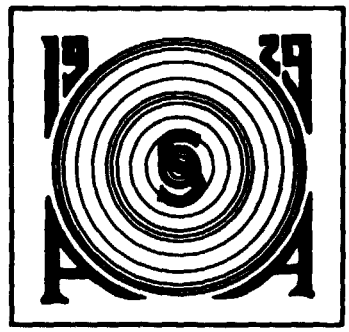

FOREWORD

[This Foreword is not a part of American National Standard Guide S2.34-1984 (ASA Catalog No. 34-1984).]

This standard Guide has been developed under the jurisdiction of Accredited Standards Committee S2 using the American National Standards Institute (ANSI) Committee Procedure. The Acoustical Society of America holds the Secretariat for Committee S2. This guide has been approved for publication by S2 and by the Acoustical Society of America Committee on Standards (ASACOS).

The scope of Standards Committee S2 on Mechanical Shock and Vibration under whose jurisdiction this standard was prepared is as follows:

> Standards, specifications, methods of measurement and test, and terminology in the fields of mechanical shock and vibration, but excluding those aspects which pertain to safety, tolerance, and comfort.

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S. Feldman
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Working Group S2-74 on Measurement of Mechanical Mobility, which assisted the committee in preparing this standard Guide, had the following membership:

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Suggestions for improvement of this standard Guide will be welcomed. They should be sent to the Standards Secretariat, Acoustical Society of America, 335 East 45th Street, New York, NY 10017.

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0 INTRODUCTION

0.1 Introduction to the Set of ANSI Mobility Measurement Documents

Dynamic characteristics of structures can be determined as a function of frequency from measurements of mobility or of the related frequency response functions called accelerance and dynamic compliance. Each of these frequency response functions is a ratio of the motion response of a structure to the excitation force or moment at a single point. The magnitude and the phase of these ratios are functions of frequency.

Accelerance and dynamic compliance differ from mobility only in that the motion response is expressed in terms of acceleration or displacement, respectively, instead of in terms of velocity. To simplify the standards, only the term "mobility" will be used. It is understood that all test procedures and requirements described are applicable also to the determination of accelerance and dynamic compliance.

Mobility measurements are typically used for:

(1) Predicting the dynamic response of structures to known or assumed input excitation;
(2) Determining the modal properties of a structure (natural frequencies, mode shapes, and damping ratios);
(3) Predicting the dynamic interaction of interconnected structures;
(4) Determining dynamic properties (i.e., the complex modulus of elasticity) of materials in pure or composite forms;
(5) Checking the validity and improving the accuracy of mathematical models of structures.

For some applications, a *complete* description of the dynamic characteristics may be required considering translational forces and motions along three mutually perpendicular axes, as well as moments and rotational motions about these three axes. This results in a 6×6 mobility matrix for each location of interest. For N locations on a structure, the system thus has an overall mobility matrix of size $6N\times6N$.

For most practical applications, it is not necessary to know the *entire* $6N\times6N$ matrix. Often, it is sufficient to measure the driving-point mobility and a few transfer mobilities by exciting with a force at a single point in a single direction and measuring the translational response motions at key points on the structure. In other applications, only rotational response to moment excitation around a single axis may be of interest.

In order to simplify the use of standards for the varied mobility measurement tasks encountered in practice, a set of ANSI documents on mobility measurement will be published in five separate parts:

Part I (ANSI S2.31-1979) covers basic definitions and transducers. The information in Part I is common to most mobility measurement tasks.

Part II (ANSI S2.32-1982) covers mobility measurements using single-point translational excitation with an attached exciter.

Part III will cover mobility measurements using single-point rotational excitation with an attached exciter. This information is primarily intended for rotor system torsional resonance predictions.

Part IV (the present Guide) covers measurements of the entire mobility matrix using attached exciters. This includes the translational, rotational, and combination terms required for the 6×6 matrix for each location on the structure.

Part V will cover mobility measurements using impact excitation with an exciter which is not attached to the structure.

NOTE: At the time when Part IV was published, Parts III and V were in preparation. Part IV is published as an ANSI Guide, whereas Parts I and II are ANSI standards.

Mechanical mobility is defined as the frequency response function formed by the ratio of the phasor of the translational or rotational response velocity to the phasor of the applied force or moment excitation. If the response is measured with an accelerometer, conversion to velocity is required to obtain the mobility. Alternatively, the ratio of acceleration to force or moment, called accelerance, may be used to characterize a structure. In still other cases, dynamic compliance, the ratio of displacement to force or moment, may be used.

NOTE: Historically, frequency response functions of structures have often been expressed in terms of the *reciprocal* of one of the above-named dynamic characteristics. The arithmetic reciprocal of mechanical mobility has often been called mechanical impedance. It should be noted, however, that this is misleading because the arithmetic reciprocal of mobility does *not*, in general, represent any of the elements of the impedance matrix of a structure.

Mobility test data cannot be used directly as part of an impedance model of the structure. To achieve compatibility of the data and the model, the impedance matrix of the model must be converted to mobility, or vice versa.

0.2 Introduction to Part IV of the Set (American National Standard Guide S2.34-1984)

In the dynamic analysis of complex structures there may arise occasions when either the rotational response or the coupling between translation responses and rotational responses is critical and the methods described in Parts I and II of this set of ANSI documents are inadequate for determining the dynamic behavior of structural systems. These situations require a complete dynamic description of all the relevant degrees of freedom of the critical points in the structure in order to assess potential problems or recommend appropriate corrective action.

In these situations, it may be necessary to employ generalized measurement techniques that have been developed to determine any element of the mobility matrix describing the passive multidirectional vibration characteristics of points on a structure as a function of the frequency of vibration. The present guide is concerned with the measurement of rotational mobility properties as well as the complete mobility matrix and the inherent limitations of the currently available measurement methods.

The state of the art of measurements of rotational mobility properties of structures is still very much in flux. For this reason, Part IV of the set of ANSI documents is published as an American National Standard Guide rather than as an ANSI standard. As the state of the art matures, replacement of this Guide by an ANSI standard will be considered. In the meantime, this guide will provide guidance to those needing to measure rotational mobility properties of structures.

Consideration of mobilities in more than one direction leads to an appreciation of some of the limitations of conventional mobility testing. In particular, if a structure is not symmetrical or is not excited through its mass center, there will often be a significant response in directions other than that in which the excitation is being applied. If this effect is not properly allowed for, erroneous results can easily be obtained. For example, in measuring the mobility at the end of a simple cantilever beam, it is found that there is a significant rotational response to an applied transverse force. In most cases, the vibration exciter and its connection are not completely free to accommodate this rotation, and, as a result, they impose a restraint on it. This is equivalent to applying a moment to the end of the beam in addition to the intended force. This moment is not measured, but the response which is measured is the sum of that generated by the force and the moment and is not the information which is sought. In order to overcome this difficulty, it is generally sufficient to incorporate a "decoupling rod" between the vibration exciter and the structure which has a low stiffness in all directions other than that in which it is desired to apply excitation and accordingly, this has been adopted as standard practice. (See ANSI S2.32-1982, Sec. 5.3.)

1 PURPOSE AND SCOPE

1.1 Purpose

This guide delineates the methods and procedures which may be used to determine the structural mobility properties, translational and rotational, of a system of points on a structure. This guide is to be used for guidance only, since the state of the art is still in flux.

NOTE: The term "point" as used in this guide designates a location only. Each "point" has six coordinates (three translational and three rotational). The term "degree of freedom" is used in this report to designate these coordinates (see Fig. 1).

1.2 Scope

This guide is limited to the determination of mobility properties of structures derived from the complex amplitudes of translational and rotational responses and the complex amplitudes of excitation forces and moments within the audio frequency range.

1.3 Related Standards

This guide is coordinated with the following standards which are closely related to mobility measurements:

American National Standard Methods for the Experimental Determination of Mechanical Mobility, Part I: Basic Definitions and Transducers S2.31-1979